MODIS
Terra Sea Surface Temperture
Thermal (sst) and mid-infrared (sst4)
Data Quality Summary

Investigation: MODIS

Data Product: Sea surface temperature (MOD25)

Data Set: Terra

Data Set Version: 3

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Nature of the product

MODIS has a number of infrared bands in the mid- and far-infrared which were placed to optimize their use for SST determination. Bands of particular utility to infrared SST determination are listed in Table 1.

Table 1. Bands for MODIS Infrared SST Determination

Band Number Band	Center (μ)	Bandwidth (μ)	NE•T (K)
20	3.750	0.1800	0.05
22	3.959	0.0594	0.07
23	4.050	0.0608	0.07
31	11.030	0.5000	0.05
32	12.020	0.5000	0.05

These bands were chosen for MODIS based on particular aspects of the atmospheric total column transmissivity in each part of the mid- and far-infrared spectrum. The bands located near 4μm (20, 22, and 23) exhibit high sensitivity and are placed where the influence of column water vapor is minimal on the sensed radiances. Bands in the far-infrared between 10μm and 12μm (31 and 32) are located near the maximum emission for a 300K blackbody (an approximation for the average Earth temperature) and placed such that there is a significant difference in the band integrated water vapor absorption for the two bands. The mid-infrared bands, while having minimal water vapor loading, suffer from decreased available Earth radiance, narrow bandwidth and possible specularly reflected solar radiance during daylight. The far-infrared bands are near the maximum of the Earth's emission and have larger bandwidth, but are burdened by large water vapor absorption in the tropical air narrow bandwidth and possible specularly reflected solar radiance during daylight. The far- infrared bands are near the maximum of the Earth's emission and have larger bandwidth, but are burdened by large water vapor absorption in the tropical air masses. The mid- and far-infrared bands differing sensitivity to total column water vapor complement each other and provide a balanced infrared SST observing strategy.

The algorithms for determination of SST from both the thermal and mid-infrared bands are detailed in the (MOD25) ATBD available at
http://modarch.gsfc.nasa.gov/MODIS/ATBD/atbd_mod25.pdf.

Thermal infrared algorithm (10 -12 µm): modis_sst

The basis for the MODIS V.2 SST algorithm is the Miami Pathfinder SST (mpfsst) algorithm, developed at UM-RSMAS [Kilpatrick et. al., 2001], which is:

$$modis\_sst = c1 + c2 * T31 + c3 * T3132 * SST_{guess} + c4 * (\sec(q) - 1) * T3132$$

T30 is the band 31 brightness temperature (BT)
T3132 is (Band32 - Band31) BT difference
SST_{guess} is the first guess SST
q is the satellite zenith angle

The algorithm differentiates atmospheric vapor load using the difference between the brightness temperatures (T3132) for the 11 and 12 µm bands (MODIS bands 31 and 32). The daytime SST algorithm use the Reynolds weekly OI as the first guess SST, while the nighttime algorithm uses the SST4 product as the first guess SST.

Ideally coefficients (c1, c2, c3, c4) are determined by regression analysis from radiative transfer simulations or a large matchup database of satellite brightness temperatures and *in situ* radiometric measurements. Until a large number of MODIS matchups are available coefficient estimation for the Provisional algorithm currently uses a regression analysis between MODIS brightness temperatures and Pathfinder SST products.

Mid-range infrared algorithm (3.7– 4.2 µm): modis_sst4

The MODIS is the first spacecraft radiometer to have several infrared bands in the 3.7-4.1µm atmospheric window with characteristics suitable for the derivation of SST. This window is more transparent than that at 10-12 µm (bands 31 and 32) and provides the opportunity to derive more accurate SST fields. Although heritage instruments have had single channels in this window, the data from which have been used in conjunction with those from the longer wavelength window to derive SST [e.g. Llewellyn-Jones et al., 1984], MODIS provides the first opportunity to derive SST using measurements in this window alone.

The main disadvantage of this spectral interval for SST measurements is the contamination of the oceanic signal by reflected solar radiation in the daytime. Because of the wind roughening of the sea surface the reflection of the insolation becomes spread out over a large area when viewed from space – the sun-glitter pattern [e.g. Cox and Munk, 1954]. This can render a large fraction of the daytime swath unusable for SST determination. As a consequence, algorithms using measurements in this interval have been restricted to night-time use, or to those parts of the daytime swath where the risk of solar contamination can be confidently discounted. Thus, while the MODIS bands 20, 22 and 23 offer radiometric advantage over bands 31 and 32, they cannot offer the day and night applicability of the longer wavelength bands. The SST4 algorithm is based on a linear formulation which is:

$$SST4 = c1 + c2 * T22 + c3 * (T22 - T23)$$

T22 is the Brightness temperature in band 22
T23 is the Brightness temperature in band 23

Coefficients (c1, c2, c3) for the at-launch Beta SST and SST4 algorithms were estimated by radiative transfer modeling. For reasons that are currently unclear, this modeling approach produced poor results and very large biases (~4C) as a function of scan angle (SST4) and (~2C) over the 0-30C temperature range for SST, when compared to Pathfinder SST. Coefficients for the Provisional algorithm were therefore developed using a regression analysis of brightness temperature and Pathfinder SST at selected locations and MODIS viewing geometry. The regressive approach to coefficient estimation has dramatically improved both the SST and SST4 products. Generally the Provisional SST4-SST MODIS product difference is <0.8ºC. We continue to investigate why the radiative transfer method did not produce reasonable results.

Cautions When Using Data

Given well calibrated radiances from MODIS, deriving accurate sea surface temperature fields and associated statistics is dependent on one's abilities to correct for the effects of the intervening atmosphere on these spectral radiances and to provide assimilation mechanisms which cover the time-space windows of interest. Sensing SST through the atmosphere in the thermal infrared is subject to several environmental factors that degrade the accuracy of the perceived temperature. Major sources of error in the radiometric determination are (a) sun glint (MODIS bands 20, 22, and 23), (b) water vapor absorption in the atmosphere (MODIS bands 31, 32), (c) trace gas absorption (all bands) and (d) episodic variations in aerosol absorption due to volcanic eruptions, terragenous dust blown out to sea, etc. (all bands). Although satellite radiometers sense the ocean's radiation temperature known as "skin" temperature, satellite results are commonly compared with bulk temperature measurements in the upper several meters of the ocean. Air-sea interaction modifies the relationship between these two variables and causes observable differences in the bulk and radiation temperatures [Robinson, et al., 1984; Cornillon and Stramma, 1985; Schluessel et al.,1990].

Sensor on-orbit characterization and calibration continues to be an important issue. Detailed information on known sensor problems and characteristics can be found at http://modis-ocean.gsfc.nasa.gov/qa/knownprobsrep.html.
Currently identified artifacts that impact SST and SST4 accuracy/uncertainty include; detector to detector variations, response versus scan angle (RVS), mirror side differences, angle of incidence (AOI), and digitizer noise. Tremendous progress has been made in decreasing the presence of these artifacts in Provisional product algorithms, however they have not been completely eliminated.

Expected Revisions
The revisions in the processing code will mainly reflect improvements in the on-orbit characterization of MODIS. In particular, as more validation data become available, they will provide better understanding of the MODIS response-versus-scan-angle effects, detector-to-detector sensitivity variation, and improved algorithm coefficient estimations from the matchup database of buoy and M-AERI *in-situ* measurements. Comparison to the AVHRR pathfinder products and other climatologies will also be analyzed to determine the accuracy and uncertainty in the MODIS SST and SST4 products. As this understanding leads to improvement of the processing, this document will be updated to reflect the expected data accuracies.

Quality Assurances
There are four levels of quality for the *SST and SST4 products*. These are based on the values of certain flags related to (http://modis-ocean.gsfc.nasa.gov/qa/). There are two kinds of flags – Common flags and Product Specific flags. Most of the Product flags are for sensor diagnostics or cloud detection, others reflect some failure of the processing.

In the common flag, bits are set as follows:
Bit 1 – Pixel not processed
Bit 2 – Atmospheric correction failed
Bit 3 – Satellite zenith angle > 55 Deg.
Bit 4 – Solar zenith angle > 70 Deg.
Bit 5 – Shallow water
Bit 6 – Sun glint (predicted reflectance > threshold)
Bit 7 – Invalid or missing ancillary data
Bit 8 – Land

In Product specific flag bytes, bits are set as follows:
Least significant byte
Bit 1- 31/32 brightness temps bad; unreasonable values in one or more bands ,-4 or >33^{o}C degrees
Bit 2 SST4 algorithm uniformity test 2 (max-min of 3x3 pixel box >0.7)
Bit 3 SST4 algorithm uniformity test 1 (max-min of 3x3 pixel box >0.1.2)
Bit 4 - SST4 algorithm zenith angle test 1; sat zenith angle > 40
Bit 5 - SST4 algorithm zenith angle test 2; sat zenith angle > 55
Bit 6 - Failed SST4 tree tests
Bit 7 - SST4 -reference greater than threshold
Bit 8 - ch20/22/23 brightness temps bad, unreasonable values <-4 or < 33
Most significant byte
Bit 9 -SST input radiance bad; negative radiance in any of bands (31,32), negative or saturated
Bit 10 -SST4 input radiances bad; negative values,negative or saturated
Bit 11 -Band 31 or band 32 failed uniformity test 1 (max-min of 3x3 pixel box >0.7)
Bit 12 -Band 31 or band 32 failed uniformity test 2 (max-min of 3x3 pixel box >1.2)
Bit 13 - SST algorithm zenith angle test 1, sat zenith angle > 40
Bit 14 - SST algorithm zenith angle test 2, sat zenith angle > 55

Bit 15 - Failed SST tree tests
Bit 16 - SST - Reynolds reference greater than threshold

Quality level definitions
The quality levels range from 0—3 according to the setting of various flags above. Quality Level 0 indicates no known problems, Quality Level 3 indicates that the data are unusable. The Quality Levels are related to the Common and Product flags as follows:

For daytime SST (thermal IR product bands 31,32) and SST4 (mid-IR products):

- Quality Level 0: No Common or Product flag bits set.
- Quality Level 1: Bit 13 -Satellite zenith angle test 1
- Quality Level 2: Common flag bit 6 (Sun Glint above threshold) set or Bit 11 failed uniformity test 1.
- Quality Level 3: Common flag Bit 8-Land, Common flag Bit 1-unprocessed, Product flag Bit 9-brightness temperature out of range, Bit-16 SST -Reynolds reference, Bit 12 -failed uniformity test 2, Bit-14 satellite zenith angle test 2.

For night time SST (thermal IR product bands 31,32) only

- Quality Level 0: No Common or Product flag bits set.
- Quality Level 1: Bit 13 -Satellite zenith angle test 1, Bit-11 uniformity test 1, 0.8<(SST-SST4) <1.0
- Quality Level 2: Bit 12 failed uniformity test 2, Bit - 14 satellite zenith angle test 2, (SST-SST4) >1.0.
- Quality Level 3: Product flag Bit 9-brightness temperature out of range, Bit-16 satellite SST different than reference, Bit 12 -failed uniformity test 2, band (31-32BT)- median difference reference > threshold

For night time SST4 only:

- Quality Level 0: No Common or Product flag bits set.
- Quality Level 1: Bit 13 -Bit -4 Satellite zenith angle test 1, Bit-2 uniformity test 1, 0.8<(SST4-SST)<1.0
- Quality Level 2: Bit 3 failed uniformity test 2, Bit - 5 satellite zenith angle test 2, (SST-SST4) >1.0.
- Quality Level 3: Product flag Bit 10-band 22/23 brightness temperature negative or saturated, band (22-23BT) - median difference reference > threshold.

References

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